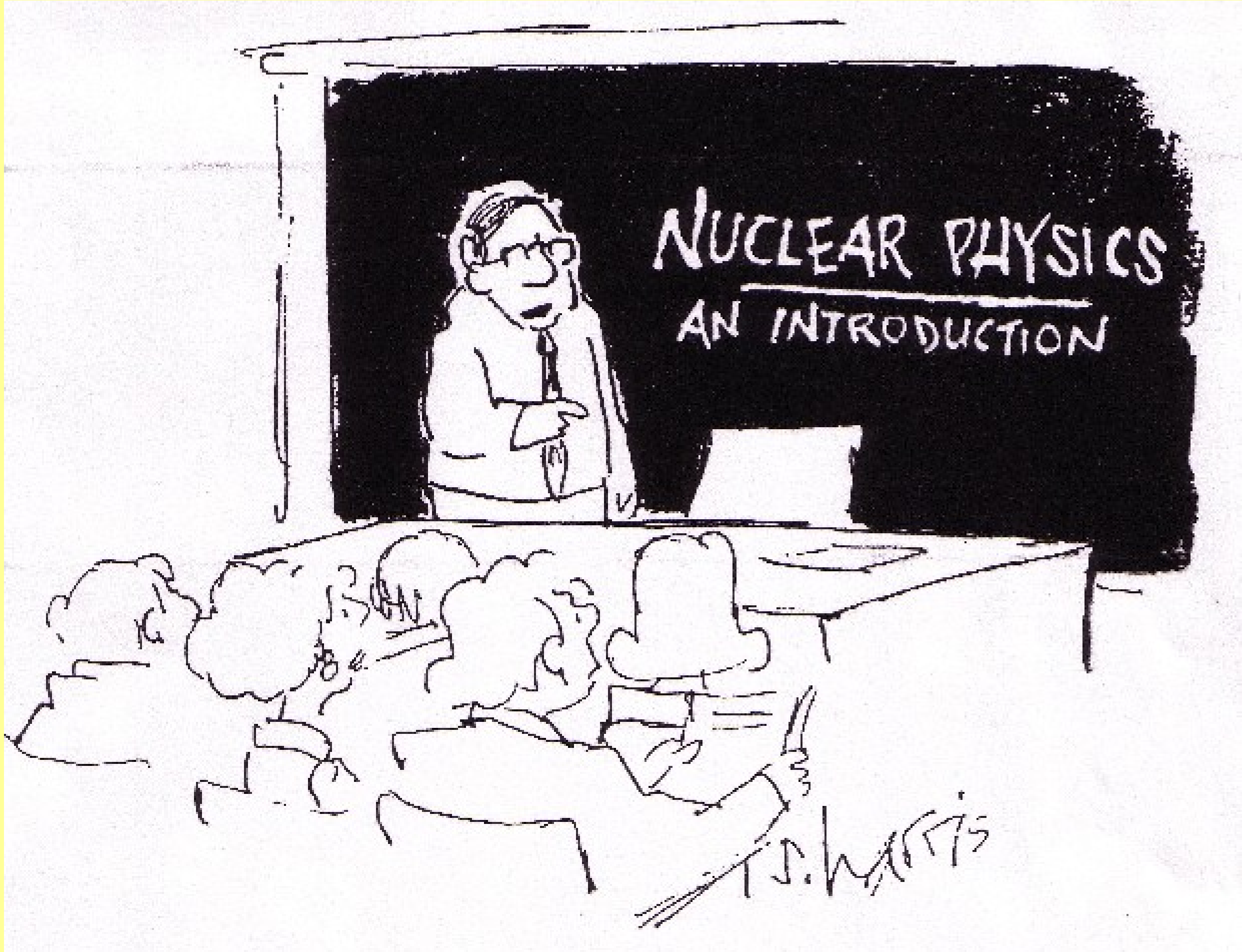


First and foremost, the word is not `nucular' !

(don't say it like George Bush!)

Class times: **Slot 9 -- Tuesdays and Thursdays, 11:30 a.m. – 12:45 p.m. in room 519 Allen**

Instructor: **Dr. S. A. Page** **Email:** spage@cc.umanitoba.ca
Office: **217 Allen** **Telephone:** **474 6202**

Consultation Times: To make an appointment, please speak to me in class, by phone or email as above. I am generally in my office from 4 – 6 pm most days. Feel free to drop in at any time for help with the course.

Textbook: **Subatomic Physics by Fraunfelder & Henley (Prentice-Hall)**

Textbook references will be given in the lecture notes, along with supplementary materials, which will be available on the course website:

http://www.physics.umanitoba.ca/undergraduate/phys451/.

Supplementary texts:
- Introductory Nuclear Physics, by K.S. Krane (Wiley)
- Introduction to High Energy Physics, by D.H. Perkins (Addison-Wesley)
- Nuclear and Particle Physics, by W.S.C. Williams (Oxford)

Assignments: There will be 5-6 assignments designed to illustrate the course material and to expand on some of the topics discussed in class. These will be distributed evenly throughout the term, with approximately one week allowed to complete each assignment. A thorough understanding of the homework problems will be necessary in order to perform well on the final exam. Students who experience difficulty with any of the homework are strongly encouraged to seek help directly from the instructor, well before the assignment is due. Marks will be deducted for late assignments at the rate of 10% per day; assignments more than 2 days late will not be accepted.

Examinations: There will be a one-hour midterm test in class on **Thursday, Nov. 3rd.** A 3 hour final exam will be scheduled in December.

Evaluation Procedure:	
Assignments:	**25%**
Midterm test:	**25%**
Final Exam:	**50%**
Total:	**100%**

Policy on Plagiarism and Cheating: The University of Manitoba policy on plagiarism and cheating is found on page 27-8 of the Undergraduate Calendar.

I. The Proton

Static properties: charge, mass, spin, magnetic moment
Electromagnetic structure: electron scattering
Excited states
Deep inelastic scattering and the quark model

II. The Neutron

Static properties and electromagnetic structure
Beta decay: $n \rightarrow p + e + \nu_e$ and the Standard Model
Weak interaction and neutrinos

III. The Two-Nucleon System

Deuterium: static properties and binding energy
Quantum numbers for the two-nucleon system; isospin
Nucleon-nucleon scattering, interaction model

IV. Finite Nuclei

Static ground state properties
Semi empirical binding energy model
Nuclear beta decay
Nuclear shell model
Collective Models of nuclei

Overview

- Nuclear physics as a subject is about 100 years old – since Rutherford's model of the atom (1911), and Chadwick's discovery of the neutron (1932), we have learned a great deal about the sizes, shapes, excitation spectra, and decay modes of nuclei.

- Typical nucleus is a fuzzy sphere a few x 10^{-15} meters in radius   (Unit: 1 fm = 10^{-15} m)

- **Labelling scheme:**

$$ {}^{A}_{Z}X_{N} $$

(F&H, sec. 5.9)

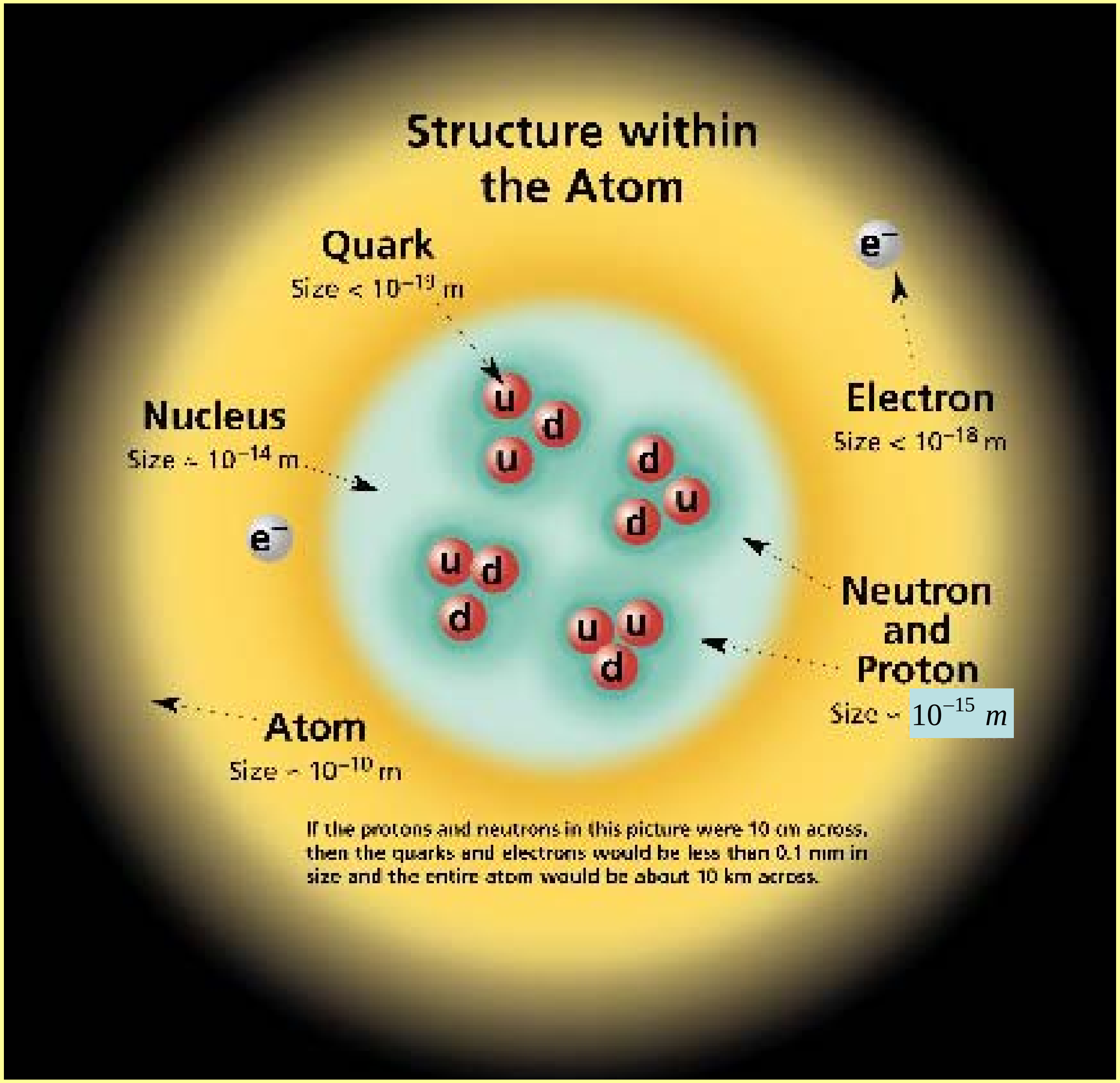
where A = mass number,   Z = proton number, N = (A-Z) = neutron number, and X is the chemical symbol

- **Naming scheme:**

Nuclei with the same	**A**	are called	**isobars**	
"	"	**Z**	"	**isotopes**	*(p for proton!)*
"	"	**N**	"	**isotones**	*(n for neutron)*

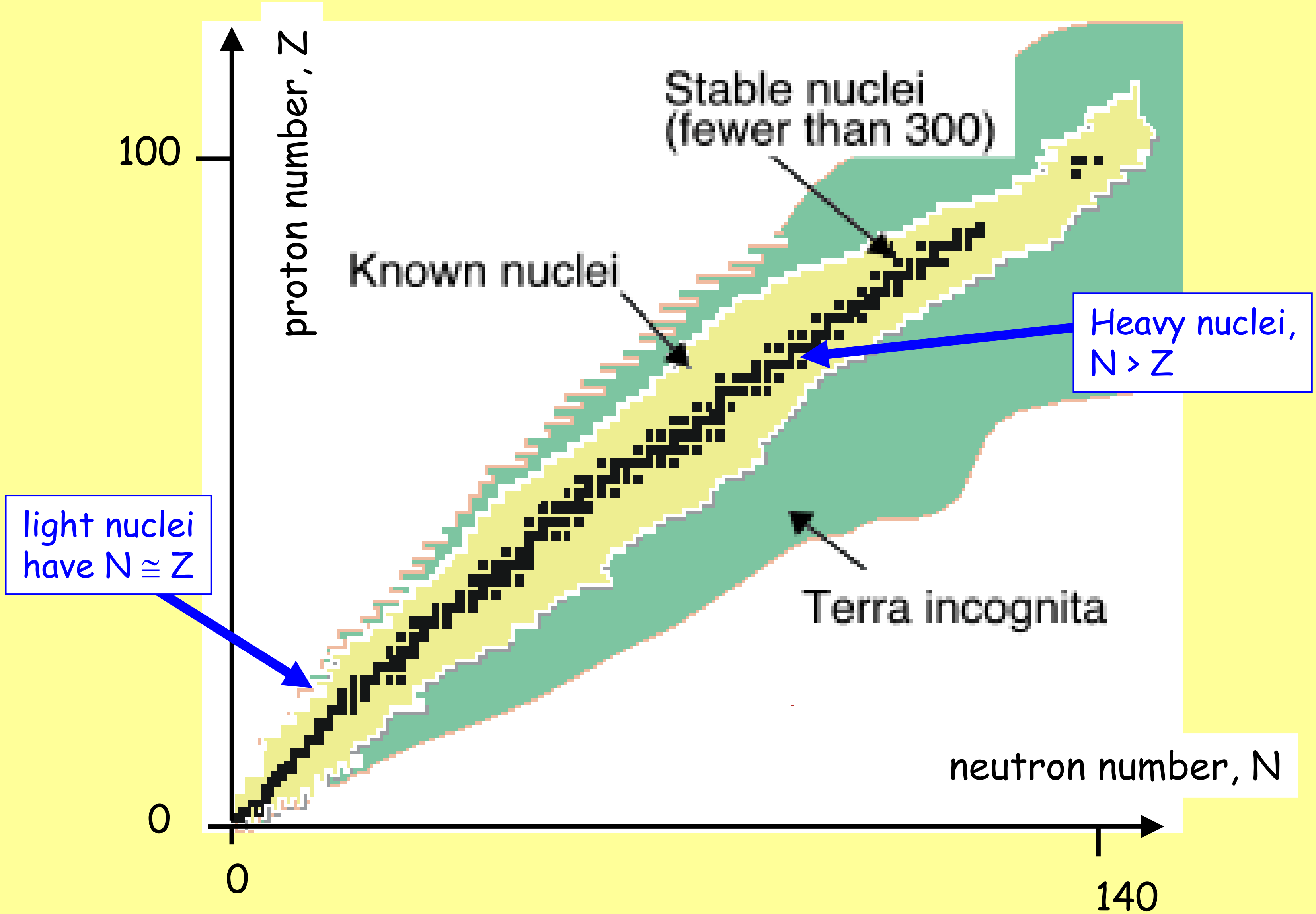
- Approx. 300 stable nuclei and many hundreds of unstable nuclei have been studied, and their properties can be understood in terms of modern theories.

Contemporary picture – APS DNP Nuclear Wall Chart:



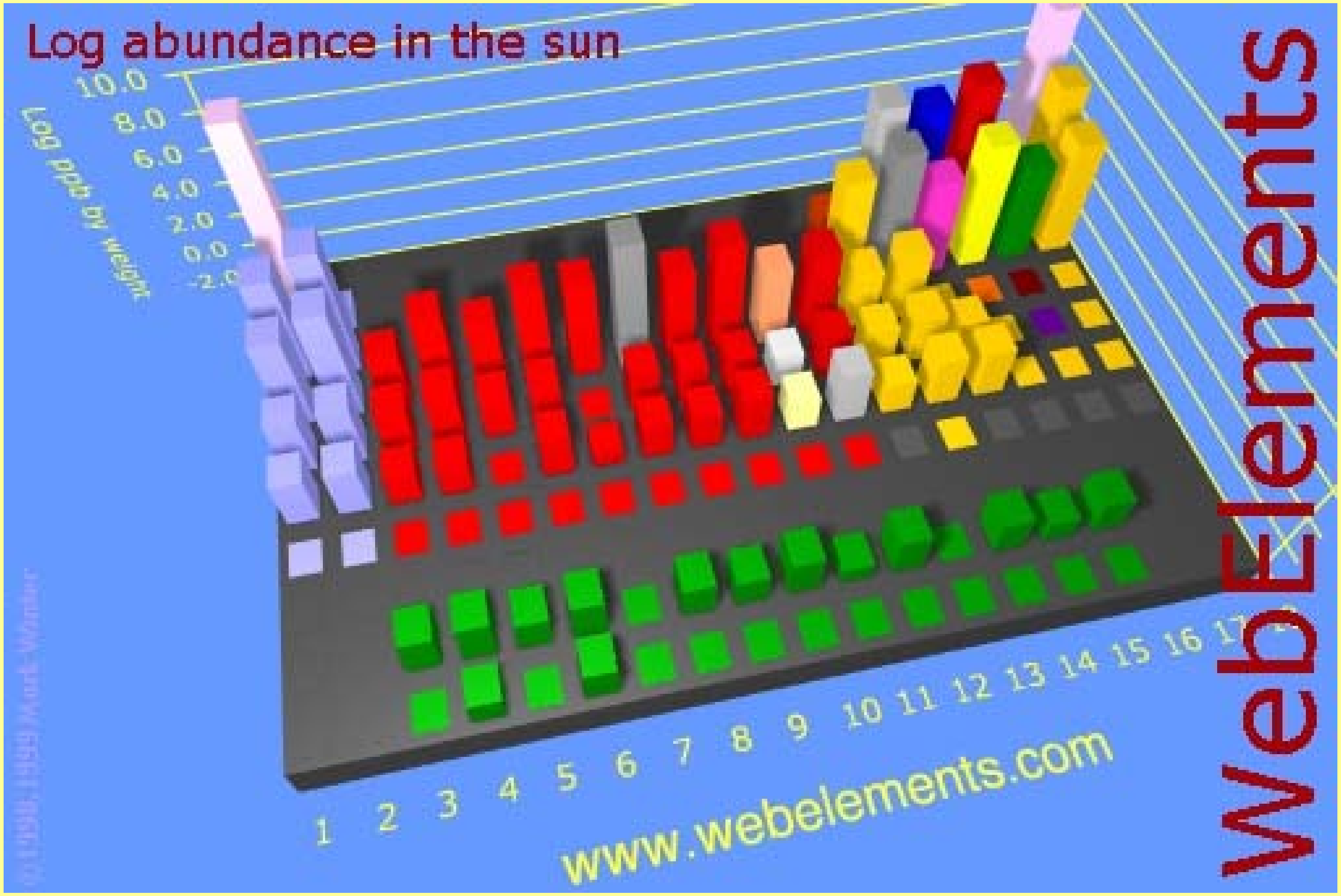
http://www.lbl.gov/abc/wallchart/index.html

Landscape of stable and unstable nuclei:



http://www.nscl.msu.edu/future/ria/science/toi.php

Abundance in Nature – a problem to explain stellar nucleosynthesis!



(F&H, chapter 19)

- Nuclei are held together by the "strong interaction", which, at the microscopic level, is a strongly attractive short range force between **quark** constituents of matter, mediated by the exchange of virtual particles called "**gluons**". The strong interaction theory is known as "quantum chromodynamics" or QCD.

- QCD has the property that the potential energy between a pair of quarks **increases** as their separation increases – this leads to the property of "confinement" – isolated quarks are never observed in nature, but only their bound states, eg protons, neutrons

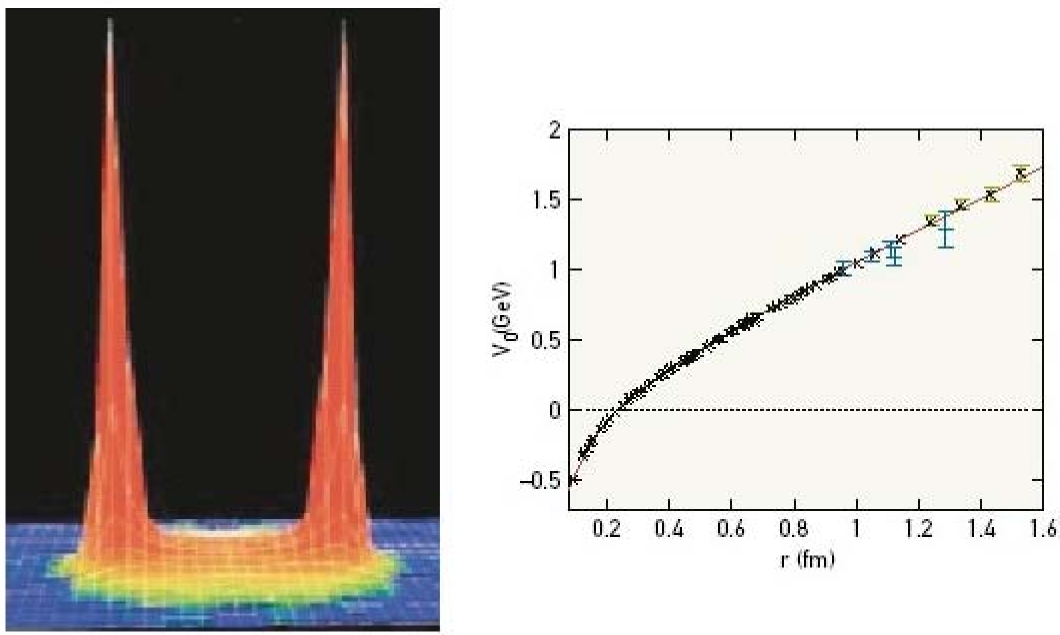


Figure 2.7. Fields of color. Lattice QCD has confirmed the existence of flux tubes between distant, static massive charges (left). The constant-thickness flux tube between the two quarks leads to a potential that rises linearly as a function of separation (right).

from "Opportunities in Nuclear Science", US - DOE Long Range Plan, April, 2002

• While there exists an “exact” theory of QCD, it is unfortunately too complicated to solve for the properties of its bound states, not even the basic proton and neutron, although progress is steadily being made with large scale numerical simulations

• Despite decades of effort, nobody has yet succeeded at deriving the nuclear force from QCD, so nuclei are described by phenomenological models and an effective theory, guided by experimental data.

Comment –

The nuclear force is much weaker than QCD -- after all, free protons and neutrons exist, while free quarks do not --

it must arise from QCD as a “residual force” similar to the weak binding of molecules (van der Waals force) compared to the relatively strong binding of electrons in atoms (Coulomb potential).

• Despite the lack of a “fundamental”, solvable theory, nuclear models have been remarkably successful at describing the structure and properties of many stable and unstable nuclei, including an amazing range of nuclear excitation phenomena, as we will see in the lectures ahead.

Fundamental interactions in nuclei *(2 protons, 1 fm apart)*

1. Strong interaction (QCD) scale: 1

    - responsible for nuclear binding
    - alpha decay, nuclear fission and fusion processes

2. Electromagnetic interaction scale: 0.01

    - correction to binding energies, N>Z for heavy nuclei
    - gamma decay of excited states

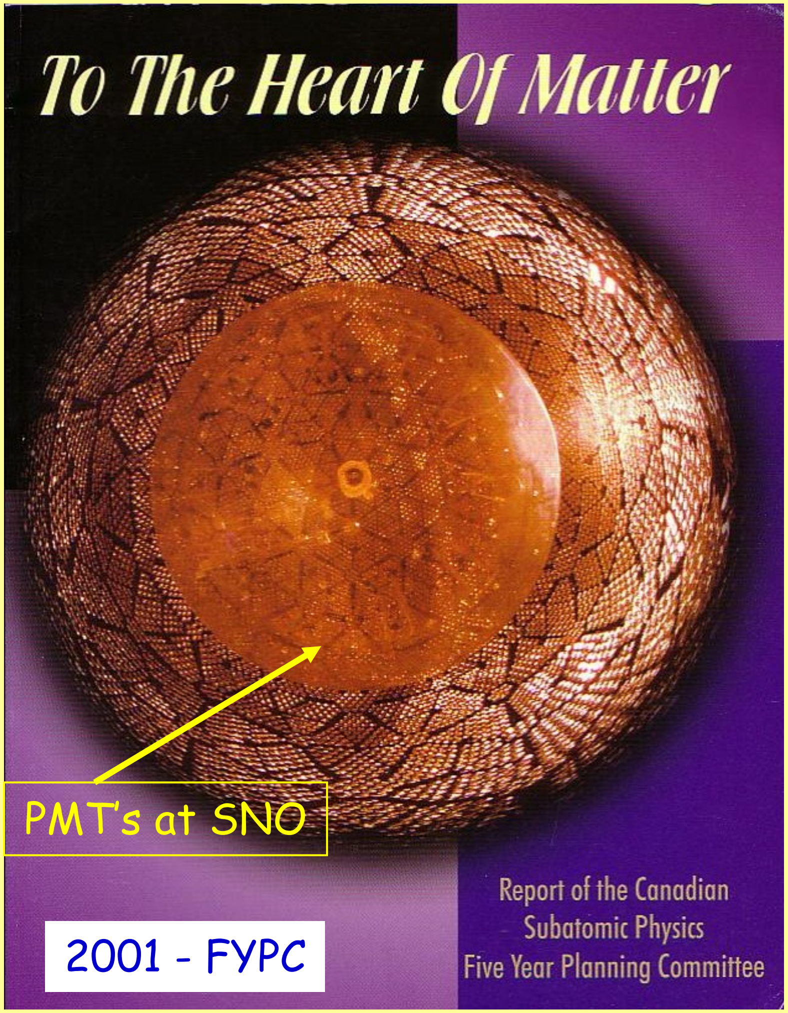
3. Weak interaction scale: 0.0000001

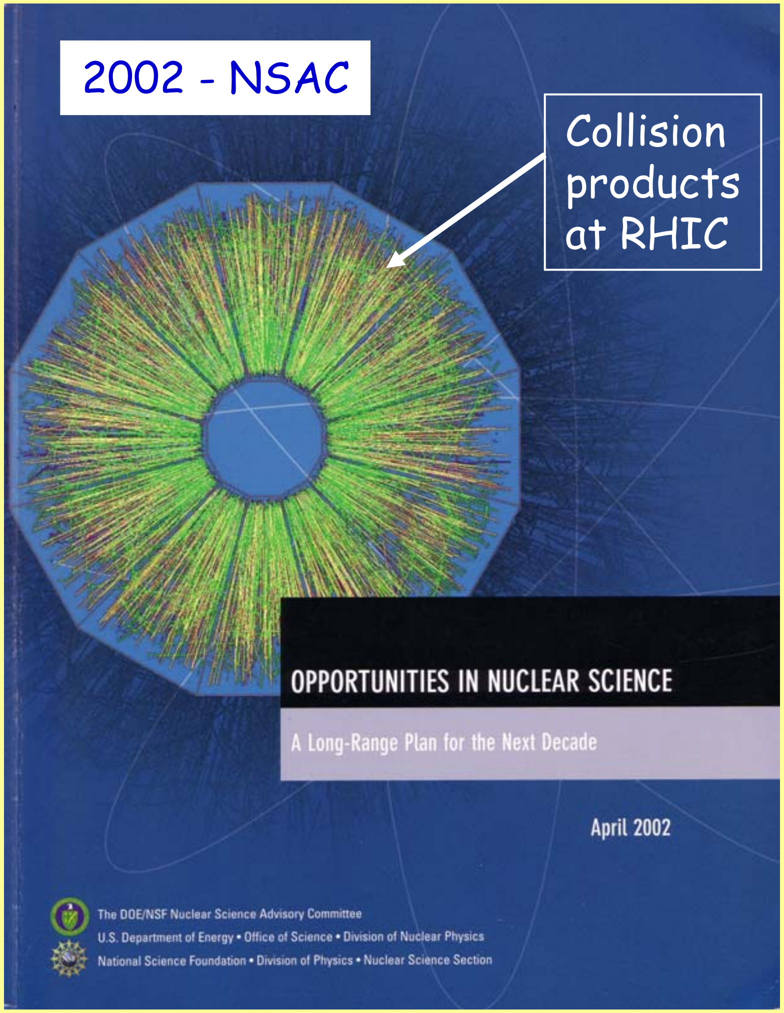
    - nuclear beta decay
    - mirror symmetry violation

4. Gravitational interaction scale: 10^{-36}

    - forget it!

Research frontiers





Most recent long range planning reports: FYPC (Canada), NSAC (USA)

→ Canada is currently engaged in a new 5 year planning exercise for subatomic physics

• The boundaries between "particle" and "nuclear" physics are somewhat fuzzy. One frontier remains, as always, the attainment of higher and higher energy scales for laboratory-based experiments to search for new particles beyond what are included in the "Standard Model" of nuclear and particle physics that we know today.
(see: http://public.web.cern.ch/public/)

• Great emphasis is being placed on precision measurements of the structure of the proton, neutron, and other relatively simple bound quark systems, with the aim of bridging the gap between QCD-based models and the underlying microscopic (but still incalculable) theory. (see e.g. http://www.jlab.org)

• "Traditional" nuclear physics spectroscopy studies are entering a renaissance with the development of new instrumentation of unprecedented resolution combined with new facilities dedicated to radioactive isotope production – the 'nuclear map' will be extended into "Terra Incognita" via experimental programs at Canada's TRIUMF-ISAC facility (http://www.triumf.ca) and others in the USA and Europe. One goal is to shed light on current problems in nuclear astrophysics, ultimately solving the problem of nucleosynthesis of elements in the universe beginning with the Big Bang and continuing with cataclysmic supernova explosions into the present day.

• With recent evidence from Canada's SNO facility (http://www.sno.phy.queensu.ca) and others that neutrinos have nonzero rest mass, there are hints that the very successful "Standard Model" of fundamental particles and interactions will soon have to be revised -- stay tuned!

Exercises:

- follow the web links suggested in class!

- find the web site and figure out how to print these notes!

- read the Overview, p. 3 – 5 and have a look at highlights of the 'Science' chapter of the US DOE Long Range Plan for Nuclear Science, available as a link on the course web site